Ocean Systems Engineering, *Vol. 12, No. 3 (2022) 285-300*
https://doi.org/10.12989/ose.2022.12.3.285

SPH simulation of solitary wave interaction with coastal structures

Guozhen Cai[1], Min Luo*[1], Zhaoheng Wei[1] and Abbas Khayyer[2]

[1]*Ocean College, Zhejiang University, Zhoushan, China*
[2]*Department of Civil and Earth Resources Engineering, Kyoto University, Kyoto, Japan*

(Received August 2, 2022, Revised September 9, 2021, Accepted September 12, 2022)

Abstract. This paper adopts the Smoothed Particle Hydrodynamics (SPH) open-source code SPHinXsys to study the solitary wave interaction with coastal structures. The convergence properties of the model in terms of particle size and smoothing length are tested based on the example of solitary wave propagation in a flat-bottom wave flume. After that, the solitary wave interactions with a suspended submerged flat plate and deck with girders are studied. The wave profile and velocity field near the surface of the structures, as well as the wave forces exerted onto the structures are analyzed.

Keywords: coastal structure; solitary wave; SPH; submerged deck; wave-structure interaction

1. Introduction

Coastal structures such as breakwaters, coastal docks and coastal bridges play significant roles in protecting the coastal areas and underpinning the economy. In practice, it is crucially important to design these structures properly such that they can survive under the actions of disastrous waves. Tsunami is a kind of disastrous wave that possesses tremendous energy and can cause serious damage to coastal structures. In this context, this paper studies the interaction between coastal structures and solitary wave, which resembles tsunami in terms of the key properties.

For investigating wave-structure interaction problems, the Computational Fluid Dynamics (CFD) modelling has been becoming prevailing due to the rapid development of computer hardware and numerical algorithms. Numerical models can be generally categorized into the mesh-based and meshless methods according to the way of discretizing the computational domain. A family of meshless methods is the so-called Lagrangian particle method that possesses advantageous features in dealing with large deformation and moving interface. According to how fluid pressure is solved, the particle methods are grouped into weakly-compressible methods and projection-based methods (imposing incompressibility strictly). The most famous and commonly-used method in the former group is the Smoothed Particle Hydrodynamics (SPH) (Amicarelli *et al.* 2020, Domínguez *et al.* 2021, Hérault *et al.* 2010, Kazemi and Luo 2022, Lyu *et al.* 2022, Monaghan 1994, Zhang *et al.* 2021a), while the latter group includes the Moving Particle Semi-implicit (MPS) method (Khayyer and Gotoh 2011, Koshizuka *et al.* 1998), Incompressible Smoothed Particle Hydrodynamics (ISPH)

*Corresponding author, Professor, E-mail: min.luo@zju.edu.cn

http://www.techno-press.org/?journal=ose&subpage=7 ISSN: 2093-6702 (Print), 2093-677X (Online)

Randles, P. and Libersky, L.D. (1996), “Smoothed particle hydrodynamics: some recent improvements and applications”, *Comput. Method. Appl. M.*, **139**(1-4), 375-408. https://doi.org/10.1016/S0045-7825(96)01090-0.
Seiffert, B., Hayatdavoodi, M. and Ertekin, R.C. (2014), “Experiments and computations of solitary-wave forces on a coastal-bridge deck. Part I: Flat Plate”, *Coast. Eng.*, **88**, 194-209. https://doi.org/10.1016/j.coastaleng.2014.01.005.
Shao, S. and Lo, E.Y.M. (2003), “Incompressible SPH method for simulating Newtonian and non-Newtonian flows with a free surface”, *Adv. Water Resour.*, **26**(7), 787-800. https://doi.org/10.1016/S0309-1708(03)00030-7.
Shimizu, Y., Khayyer, A. and Gotoh, H. (2022), “An enhanced incompressible SPH method for simulation of fluid flow interactions with saturated/unsaturated porous media of variable porosity”, *Ocean Syst. Eng.*, **12**(1), 63-86. https://doi.org/10.12989/ose.2022.12.1.063.
Sriram, V. and Ma, Q.W. (2021), “Review on the local weak form-based meshless method (MLPG): Developments and applications in ocean engineering”, *Appl. Ocean Res.*, **116**, 102883. https://doi.org/10.1016/j.apor.2021.102883.
Tripepi, G., Aristodemo, F., Meringolo, D.D., Gurnari, L. and Filianoti, P. (2020), “Hydrodynamic forces induced by a solitary wave interacting with a submerged square barrier: Physical tests and δ-LES-SPH simulations”, *Coast. Eng.*, **158**, 103690. https://doi.org/10.1016/j.coastaleng.2020.103690.
Wang, L., Jiang, Q. and Zhang, C. (2020), “Numerical simulation of solitary waves overtopping on a sloping sea dike using a particle method”, *Wave Motion*, **95**, 102535. https://doi.org/10.1016/j.wavemoti.2020.102535.
Wei, Z. and Dalrymple, R.A. (2016), “Numerical study on mitigating tsunami force on bridges by an SPH model”, *J. Ocean Eng. Mar. Energy*, **2**(3), 365-380. https://doi.org/10.1007/s40722-016-0054-6.
Wendland, H. (1995), “Piecewise polynomial, positive definite and compactly supported radial functions of minimal degree”, *Adv. Comput. Math.*, **4**(1), 389-396. https://doi.org/10.1007/BF02123482.
Xu, G. and Cai, C.S. (2015), “Numerical simulations of lateral restraining stiffness effect on bridge deck–wave interaction under solitary waves”, *Eng. Struct.*, **101**, 337-351. https://doi.org/10.1016/j.engstruct.2015.07.031.
Zhang, C., Hu, X.Y. and Adams, N.A. (2017), “A weakly compressible SPH method based on a low-dissipation Riemann solver”, *J. Comput. Phys.*, **335**, 605-620. https://doi.org/10.1016/j.jcp.2017.01.027.
Zhang, C., Rezavand, M., Zhu, Y., Yu, Y., Wu, D., Zhang, W., Wang, J. and Hu, X. (2021a), “SPHinXsys: An open-source multi-physics and multi-resolution library based on smoothed particle hydrodynamics”, *Comput. Phys. Commun.*, **267**, 108066. https://doi.org/10.1016/j.cpc.2021.108066.
Zhang, C., Wei, Y., Dias, F. and Hu, X. (2021b), “An efficient fully Lagrangian solver for modeling wave interaction with oscillating wave surge converter”, *Ocean Eng.*, **236**, 109540. https://doi.org/10.1016/j.oceaneng.2021.109540.

MK